Dam Removal Express Assessment Models (DREAM-1 and -2): Applications and Examinations[a]

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ABSTRACT

The two Dam Removal Express Assessment Models, DREAM-1 and -2 (Cui et al. 2006a,b), were developed for simulation of pulsed sediment transport in rivers and are equipped with modules that address issues following dam removal. DREAM-1 simulates fine sediment transport and can be used where reservoir deposits are composed primarily of non-cohesive fine sediment. DREAM-2 simulates fine and coarse sediment transport and can be used where reservoir deposits are composed primarily of coarse sediment, or in cases where the top layer of the reservoir deposit is composed primarily of coarse sediment. Here we summarize the applications of the two models and their predecessors, demonstrating their potential utility in future dam removal projects.

INTRODUCTION

The most challenging subject in a dam removal project is usually the management of the sediment deposit accumulated in the reservoir during its operation (ASCE 1997). For dam removal projects with large reservoir deposits, one-dimensional (1D) numerical sediment transport modeling is probably the most effective tool for understanding the post-removal sediment transport dynamics, due to the large spatial and temporal scales of the potential impacts. To provide tools that can be readily applied for sediment transport simulation following dam removal, Cui et al. (2006a,b) developed two 1D numerical sediment transport models, DREAM-1 and -2, based on early models developed for simulation of sediment pulses and other practical problems (e.g., Parker 1991a,b; Cui and Parker 1997, 1999, 2005; Cui et al. 1996, 2003b; Cui and Wilcox 2008). The two models were developed with the consideration that 1D numerical sediment transport models need to be applied and interpreted on a reach-averaged basis (e.g., Cui et al. 2008). This reach-averaged consideration minimizes the field data collection, and as a result, allows for express assessment evaluations of dam removal projects under most circumstances. Here we demonstrate the utilities of DREAM-1 and -2 (and their predecessors) for simulating sediment transport following dam removal or under other pulse sediment load circumstances.

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APPLICATION AND EXAMINATION OF DREAM-1 AND ITS PREDECESSORS

DREAM-1 and its predecessors are 1D numerical models for simulation of fine sediment (sand and finer) bed material transport. Application examples of DREAM-1 and its predecessors' are provided in Table 1. Four examples are discussed in more detail below.

Table 1. Summary of past application and examination of DREAM-1 and its predecessors

Case Study	Study Summary	Summary of Model Performance	References
Ok Tedi - Fly River Sediment Transport Dynamics Study †	Simulated sedimentation process in the Ok Tedi - Fly River system due to sediment disposal from mining operation.	Simulation produced aggradation process for a 150-km reach with sufficient accuracy. Simulation accuracy decreases downstream beyond the 150-km reach.	Cui and Parker (1999)
Soda Springs Dam Removal †	Simulated sediment transport process following the proposed removal of Soda Springs Dam, North Umpqua River, Oregon.	Model performance not available because the dam will not be removed due to an agreement between the owner and the agencies.	Stillwater Sciences (1999)
Klamath River dam removal preliminary study	Simulated potential sediment deposition downstream of Iron Gate Dam following the proposed removal of four dams on the Klamath River.	Model performance not available because the dams are not yet removed.	Stillwater Sciences (2004); Cui et al. (2005)
Simulation of Cui et al. (2003a) sediment pulse experiment Run 4b	Simulated an experimental run and compared model results with experimental observation.	Comparison of simulated and observed bed profile indicates that numerical simulation adequately reproduced the experimental observations.	Cui et al. (2006b)
Simulation of Cui et al. (2008) fine sediment pulse runs	Simulated three runs of flume experiments and compared simulated bed profile and sediment flux with observations.	Comparison of simulated and observed bed profile and sediment flux indicates that numerical simulation excellently reproduced the experimental observations.	Cui et al. (2008)

† Simulated with predecessor of DREAM-1

Simulation of river aggradation due to mine waste disposal: Ok Tedi Mining Ltd. (OTML) has operated a copper mine in the Western Province of Papua New Guinea since 1985. Over the past 22 years, more than 1.3 billion metric tons of rock waste and tailings have been disposed along the slopes of the adjacent mountains near the mine, of which more than half has been transported into the river system, resulting in massive aggradation in the Ok Tedi and Fly River. To assist the management of mining operation, Cui and Parker (1999) developed a 1D numerical model to predict the sediment transport dynamics in the river system, which later became the basis for DREAM-1. The model was used to simulate sediment dynamics in a 450 km reach. Comparison of modeling results with field data indicated that the model was able to relatively accurately predict channel aggradation processes in the upstream most 150 km. Details of the modeling can be found in Cui and Parker (1999), and a comparison between simulated and measured channel aggradation at two stations is presented in Figure 1.

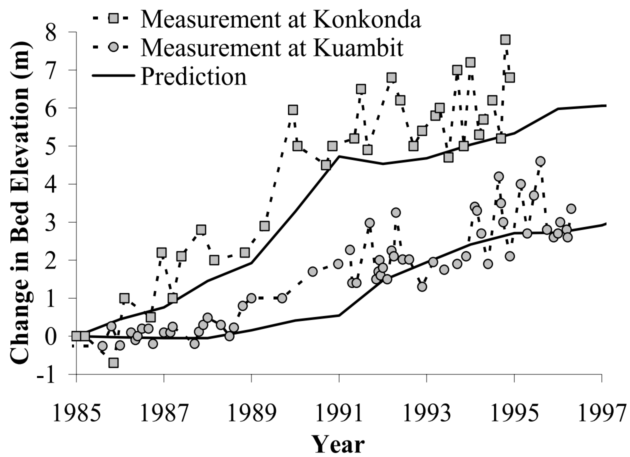

Figure 1. Comparison of simulated and measured change in bed elevation in Ok Tedi and Fly River system with a numerical model that later became the basis of DREAM-1.

Simulation of Lake Mills drawdown experiment on the Elwha River, WA: In order to validate the performance of DREAM-1, Cui et al. (2006b) simulated the Lake Mills drawdown experiment conducted by Childers et al. (2000). This examination indicated that DREAM-1 closely reproduced the rate of sediment release during the drawdown process, even though the detailed areas of sediment erosion were different between the simulation and the observation. Details of this examination can be found in Cui et al. (2006b). Comparison of simulated and measured sediment release during the 18-day drawdown experiment is provided in Figure 2.

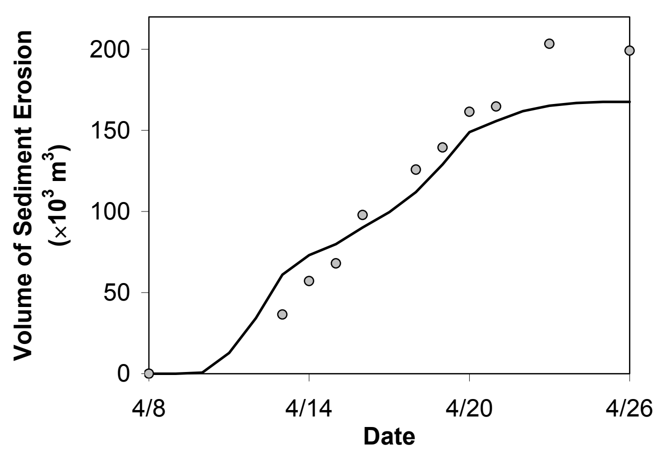

Figure 2. Simulated volume of sediment erosion during Lake Mills drawdown experiment (solid line), in comparison with field measurements (symbols). See Cui et al. (2006b) for details.

Examining DREAM-1 with experimental data: In addition to model examinations against field data, Cui et al. (2006b, 2008) also examined DREAM-1 performance with several sets of flume data. Cui et al. (2006b) found that DREAM-1 was able to adequately simulate erosional and depositional patterns of an experimental fine sediment pulse movement over a gravel bed, with minimal model calibration, and Cui et al. (2008) show that DREAM-1 was able to accurately simulate all the four runs of fine sediment pulse movement through an armored gravel bed with forced pool-riffle morphology on a reach-averaged basis. Details of the model examination with experimental data can be found in Cui et al. (2006b, 2008). Results for one of the runs in Cui et al. (2008) are presented in Figures 3 and 4.

Worst-case-scenario DREAM-1 simulation of potential sediment deposition in Klamath River following dam removal: With minimal field data available, Cui et al. (2005) applied DREAM-1 to evaluate the potential sediment deposition in the Klamath River, California,

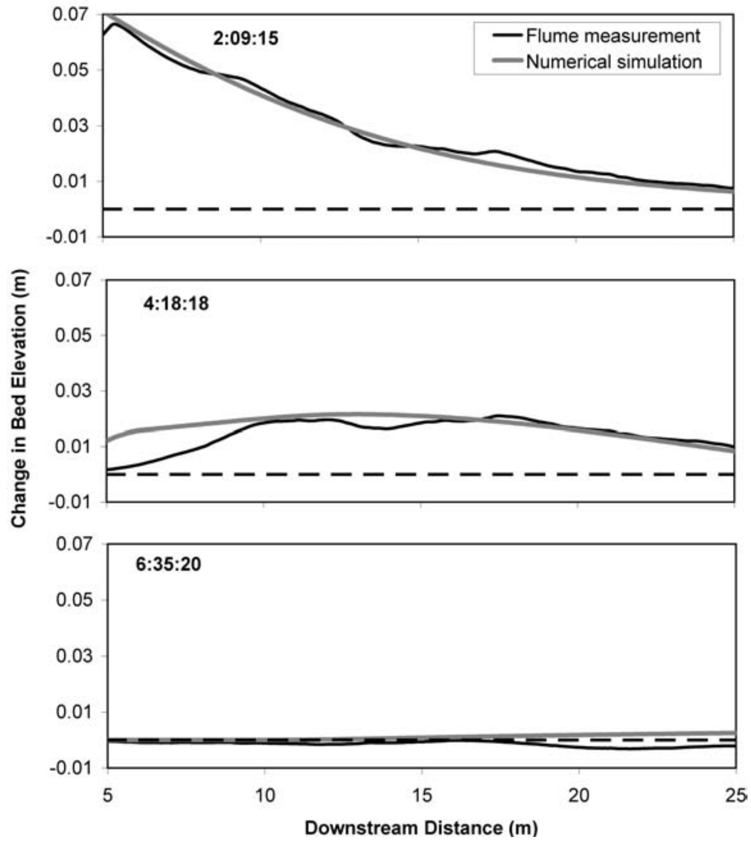

Figure 3. Simulated change in bed elevation in comparison with measured reach-averaged data for Run 7 presented in Cui et al. (2008), indicating DREAM-1 was able to simulate fine sediment transport over an armored gravel bed with forced pool-riffle morphology on a reach-averaged basis.

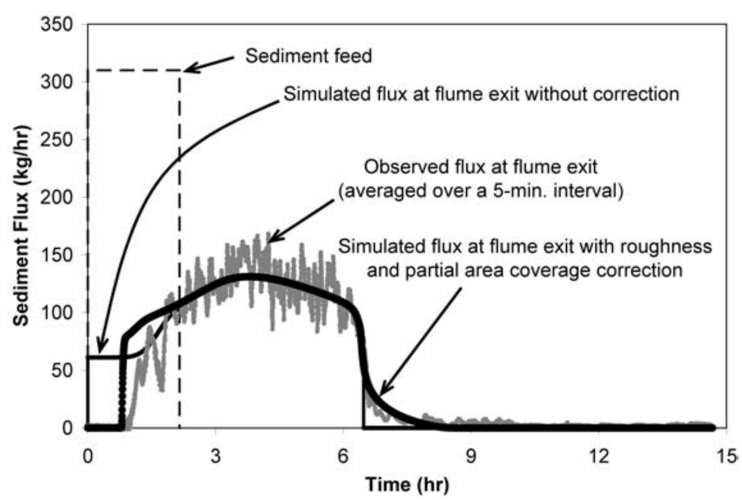

Figure 4. Comparison of simulated and measured sediment flux for Run 7 presented in Cui et al. (2008). See the original reference for details.

downstream from Iron Gate Dam, following the proposed removal of J.C. Boyle, Copco 1 and 2, and Iron Gate dams. Recognizing that the majority of the more than 12 million m^3 of reservoir deposit estimated at the time was fine sediment, and with the observation of the coarse river bed, steep slope, confined river channel and large discharge in the river, Cui et al. (2005) speculated that there would be minimal downstream sediment deposition following dam removal. They subsequently setup the model under a series of worst-case-scenario assumptions to validate this speculation. Model results confirmed that there would be minimal sediment deposition downstream from the dams, providing important information to guide management decisions and subsequent studies. This example demonstrates dam removal sediment transport models can sometimes be conducted with minimal field data collection to yield useful information. Details of this study can be found in Cui et al. (2005) and Stillwater Sciences (2004).

APPLICATION AND EXAMINATION OF DREAM-2 AND ITS PREDECESSORS

DREAM-2 and its predecessors are 1D numerical models primarily for simulation of coarse sediment (gravel and coarser) bed material transport, although DREAM-2 also includes a module for fine sediment transport. Examples of DREAM-2 and its predecessors' applications and examinations are provided in Table 2. Three examples are discussed in more detail below.

Simulation of a landslide derived sediment pulse in Navarro River, California: The sediment pulse model of Cui and Parker (2005) that later became the basis for DREAM-2 was used by Sutherland et al. (2002) to simulate the evolution of a sediment pulse generated by a landslide event in Navarro River, California, indicating the model is capable of simulating the general transport and evolution of the sediment pulse. This same sediment pulse was also simulated with DREAM-2 without model calibration to further examine its performance (Cui et al. 2006b). The net change in bed elevation simulated with DREAM-2 is presented in Figure 5, in comparison with field measurements, indicating reasonable model performance.

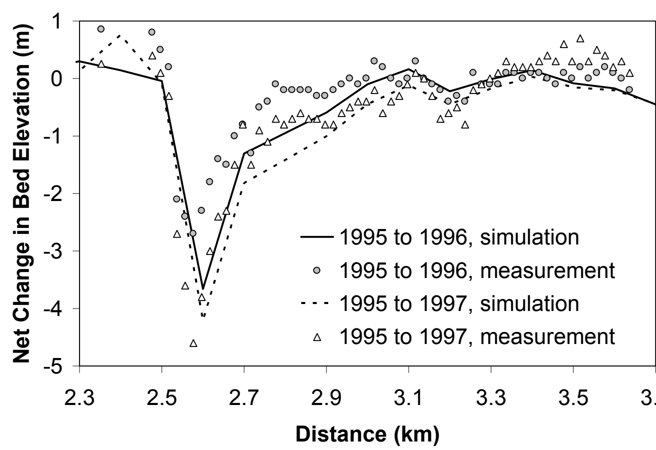

Figure 5. Comparison of DREAM-2 simulated and measured net change in bed elevation in Navarro River, CA. See Cui et al. (2006b) for details.

Examining DREAM-2 with experimental data: Cui et al. (2006b, 2008) examined DREAM-2 performance with several sets of flume data. In both cases, model results adequately matched experimental observations with minimal model calibrations. In

Cui et al. (2008), for example, DREAM-2 was able to closely reproduce the four runs of coarse sediment pulse evolution in a flume with armored bed and forced pool-riffle morphology on a reach-averaged basis. Simulated results are presented in Figures 6 and 7, in comparison with experimental data. More details about model examinations can be found in Cui et al. (2006b, 2008).

Table 2. Summary of past application and examination of DREAM-2 and its predecessors

Case Study	Study Summary	Summary of Model Performance	References
Navarro River landslide simulation ††	Simulated the evolution of a landslide-derived sediment pulse in Navarro River, CA.	Comparison of simulated and observed bed profile indicates that numerical simulation adequately reproduced the field observation.	Sutherland et al. (2002); Cui et al. (2006b)
Marmot Dam removal study †	Simulated the sediment transport process in the Sandy River, OR following Marmot Dam removal.	Field data collection on going.	Stillwater Sciences (2000, 2002); Cui and Wilcox (2008)
Saeltzer Dam removal study †	Simulated sediment transport process in the Clear Creek, CA following the proposed removal of Saeltzer Dam.	Comparison of simulated and observed bed profile indicates that numerical simulation produced the correct magnitude of sediment deposition but the simulated advancement of the sediment pulse is slower than the observation.	Stillwater Sciences (2001).
Simulation of SAFL sediment pulse runs ††	Simulated three runs of flume experiments and compared simulated bed profiles with observations	Comparison of simulated and observed bed profiles indicates that numerical simulation adequately reproduced the experimental observations.	Cui et al. (2003b); Cui et al. (2006)
Simulation of RFS coarse sediment pulse runs	Simulated four runs of flume experiments and compared simulated bed profile and sediment flux with observations.	Comparison of simulated and observed bed profile and sediment flux indicates that numerical simulation excellently reproduced the experimental observations.	Cui et al. (2008)

† Simulated with predecessor of DREAM-2;
†† Simulated with both DREAM-2 and its predecessor.

Numerical simulation of sediment transport in Sandy River, Oregon following Marmot Dam removal: Cui and Wilcox (2008) applied a modified Cui and Parker (2005) model, which later became the basis of DREAM-2, to simulate the sediment transport dynamics in Sandy River, Oregon following the removal of the 15-m tall Marmot Dam.

Several dam removal alternatives, including a one-shot removal (i.e., remove the dam in one season with minimal dredging), staged removal, and partial dredging, were examined with the model.

Modeling results indicated that staged removal would provide no benefit compared with the much more economic one-shot removal alternative, and dredging 13% of the 750,000 m^3 of sediment (the most that can be removed in one season) would give minimal reduction of channel aggradation. Modeling results also indicated minimal increase in suspended sediment concentration following dam removal, with the highest increase during storm events on the order of several hundred ppm. Largely because of the

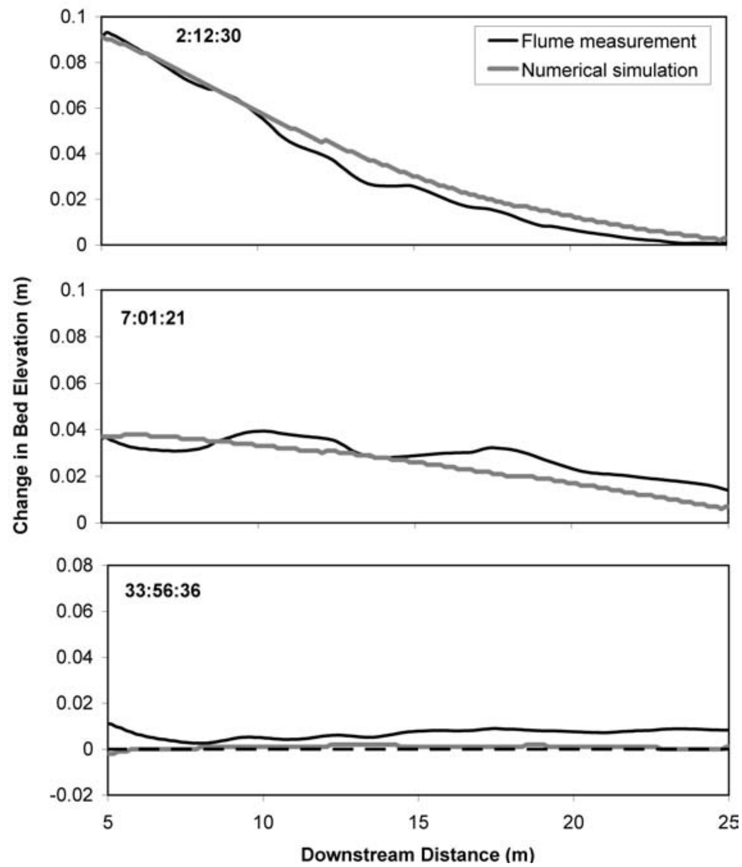

Figure 6. Simulated change in bed elevation in comparison with measured reach-averaged data for Run 8 presented in Cui et al. (2008), indicating DREAM-2 was able to simulate sediment transport over an armored gravel bed with forced pool-riffle morphology on a reach-averaged basis. See Cui et al. (2008) for details.

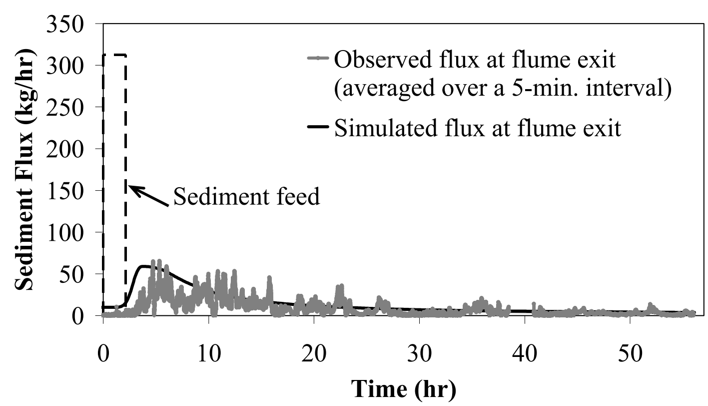

Figure 7. Comparison of simulated and measured sediment flux for Run 8 presented in Cui et al. (2008). See the original reference for details.

sediment transport modeling results, the stakeholders agreed upon the one-shot removal as the preferred dam removal alternative, and the dam was removed in the summer of 2007. Sediment transport in the river resumed in October 2007 following the first storm event of the season. While data collection is still underway, casual observations following dam removal indicated minimal increase in suspended sediment concentration in the river, similar to simulated with the numerical model, and the initial erosion of reservoir sediment may have been faster than predicted with the numerical model (John Esler, personal communication, October 2007). Figure 8 provides an example of simulated channel aggradation and degradation following Marmot Dam removal. Details of the modeling can be found in Cui and Wilcox (2008) and Stillwater Sciences (2000, 2002).

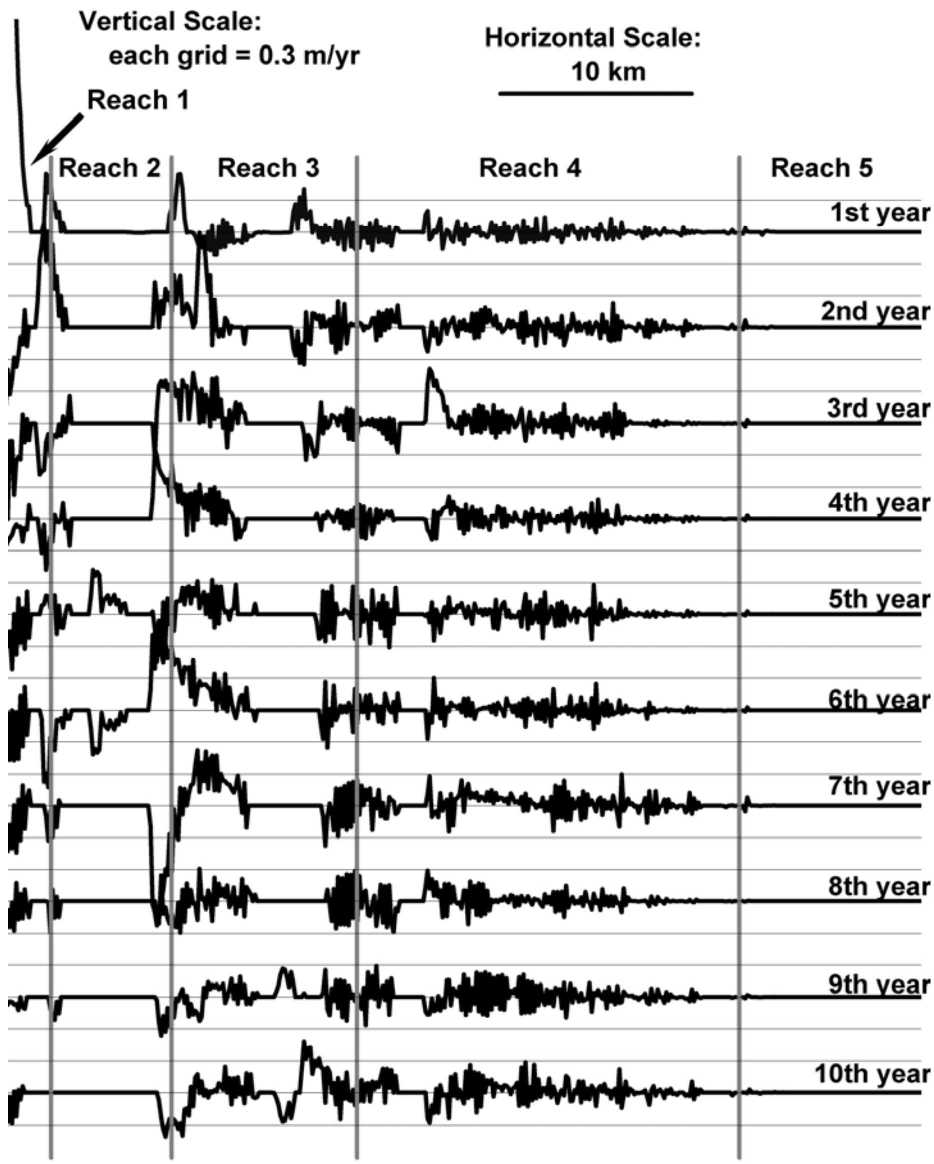

Figure 8. Simulated annual change in bed elevation in Sandy River downstream of Marmot Dam following the removal of Marmot Dam under an assumed hydrologic series. See Cui and Wilcox (2008) and Stillwater Sciences (2000) for details.

CONCLUSION

The two Dam Removal Express Assessment Models (DREAM-1 and -2) and their predecessors have been applied in several practical projects and were examined with several sets of experimental and field data. Model examinations indicate that, with minimal or even without model calibrations, the models were able to closely reproduce the experimental and field observations, indicating that they should provide relatively reliable tools for future dam removal sediment transport management evaluations. Model applications in practical projects such as OTML mining waste management, Soda Springs Dam removal, Marmot Dam removal, and the proposed removal of four dams on the Klamath River all yielded useful information to resources managers and stakeholders, allowing them to make informed management decisions such as selecting the most appropriate dam removal alternatives.

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